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Mid-IR Laboratory Operation, Maintenance and Theory Support

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14. ABSTRACT
This report summarizes the technical activity provided under task order 0015 of the SLIDERS contract. This task provided for semiconductor material processing and characterization expertise for a mid-IR semiconductor laser development laboratory, as well as computer modeling and theoretical analysis of mid-IR semiconductor laser materials and device designs. The goal of this effort was to increase the power, brightness and operating temperature of mid-IR semiconductor lasers and laser arrays. Under this task we continued the development of a semiconductor laser processing and characterization laboratory, which was used to evaluate numerous prototype laser samples and materials. Processing improvements continued which enabled us to provide better quality and repeatable laser devices. In the theory support area, we continued to develop improved methods for incorporating the effects of coherent strain, as well as more accurate electron/hole wave function predictions and have applied these methods to several InAs-

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TABLE OF CONTENTS

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1.0 INTRODUCTION

The SLIDERS contract encompassed several research efforts within the Semiconductor Laser Branch of the Laser Division, Directed Energy Directorate of the Air Force Research Laboratory. The scope of this contract included development, design, fabrication, procurement, management, operations and maintenance of optical, electronic, and mechanical systems, subsystems, and components. Principal efforts included theory and concept development, design analysis, laboratory operations, and semiconductor laser and diode-pumped laser development, operation and maintenance. Efforts also included the development, procurement, and operation of instrumentation to evaluate and characterize laser systems.

The objective of this task was to provide for on-going operation and maintenance support for the DELS branch mid-IR laboratories of the Directed Energy Directorate at the Air Force Research Laboratory, and to provide for theory and modeling in support of advanced mid-IR laser design and development. Operation and maintenance support included processing tasks such as lapping, polishing, cleaving, and bonding of semiconductor laser material, laser power measurements, and spectral characterization.

2.0 TECHNICAL ACTIVITIES

2.1 PROCESSING

Boeing led the work for processing of mid IR laser (InAs/InGaSb & InAs/GaSb) material. The laser material was received from the crystal grower in the form of semiconductor wafers. The wafer material required various finishing steps to turn them into useful devices and actual laser chips. Routine processing steps included wafer mounting, polishing, and thinning. Wafers were cleaved into different sizes for laser fabrication and inspected under a microscope. Individual dies were mounted either p-up or p-down depending on the test requirements. Using these techniques over the period of this task, Boeing processed numerous laser material samples in various ways depending upon the test requirements and over 125 processing procedures were completed.

In addition to the routine processing activity, we undertook to improve our processing techniques and tools. We researched methods to polish the substrate side of completed EPI grown wafers to an optical surface quality finish. We successfully developed a technique for polishing substrates to an optically fine and scratchless finish for EPI down mounting scenarios.

Other laser processing steps involved preparation for titanium and gold substrate coatings, and for various anti-reflective (AR) and high reflector (HR) facet and epitaxial coatings. Facet and other coatings on mid-IR laser devices are particularly important. Since these devices are optically pumped it is critical to provide low loss AR coatings on the pumped surfaces, and to coat the facets with AR and HR layers to improve the lasing performance of the cavity. In order to provide these coatings Boeing personnel were trained by experts at the UNM processing clean room on the use of their coating machines and on the deposition of thin film layers. In particular we became familiar with the silicon dioxide and silicon nitride coaters, and the Samco coater used to deposit multi-layer AR and HR reflective coatings.

AR and HR thin/thick film coating methods were developed by Boeing to satisfy the requirements for optical coatings on mid-IR laser materials. Photolithography, metallization and coatings were completed on numerous samples, both for electrically and optically pumped operation. The coating process is currently undergoing improvement as we continue to test a new process involving Argon plasma cleaning of facet surfaces to allow for better adhesion/performance of the coatings. We also developed a process by which AR coatings can be “adjusted” post-run to match specific (shorter) wavelength requirements.

2.2 CHARACTERIZATION

The processed laser material was characterized in a number of ways to test its electrical and optical performance. The primary means to test these devices involved optically pumping them. Boeing set up an optical pumping characterization station in lab 116 for the purpose of processing and characterizing semiconductor laser samples.

Boeing characterized laser samples using a number of different tests. These include L/I curves, spectral and photo-luminescence measurements at various cryogenic temperatures, near and far field scans in both the fast and slow axes of the devices, power-in-the-bucket measurements, duty cycle studies of epi-up and epi-down mounting, as well as power vs. time.

Boeing performed characterization tests on more than sixty four individual laser material samples and laser arrays, where many samples received several tests. All results from these tests were transmitted to the Air Force for evaluation.

As part of the characterization effort, the Fourier transform infrared spectrometer (FTIR) was upgraded to extend its temperature operating range. This involved setting up the FTIR helium Dewar, adapting and recharging the absorber for the helium cryocooler, and complete installation of a Neslab chiller, electric and plumbing fixtures. Our upgrade of the cryostat enabled us to perform absorption spectroscopy measurements at extremely low temperatures (~ 10K). Material samples R2-242,243,240 & 241 were mounted and tested in the FTIR instrument. The data was processed and the data files were delivered to the Air Force.

Other FTIR measurements included polarization/absorption measurements on 8 ML /8 ML InAs/GaSb superlattice samples which required polarization background subtraction data. We completed the absorbance on two different super lattices with varying temperatures. A master chart was complied and is now used for estimating absorbance of GaSb material with two different thicknesses at varying temperatures. Also as part of the process for depositing AR and HR coatings on laser samples the FTIR was used extensively to examine reflectivity and to estimate coating thickness and wavelength range.

A second FTIR and its components were moved to a new optical table and set up for LN2 and LH operations. The helium Dewar was machined for new mounting plates. We constructed a new platform to enable the cold head to move with multiple degrees of freedom into the beam path of the FTIR. The instrument setup was completed and we were able to achieve operating temperatures of 9.1K.

2.3 ELECTRICALLY OPERATED PUMP LASERS

In order to optically pump the mid-IR lasers, electrically operated pump lasers, lasing at 2 microns are required, which are not commercially available. To increase the availability of these pumps Boeing set up a test stand to characterize 2 micron laser material. Our setup allowed for L/I data collection using a gold plated ellipsoidal mirror and Molectron detector. Very small copper spacers and heat sinks were manufactured to mount laser bar material for a high power pump array. These parts were necessary to mount and position the bars uniformly onto a cooled heat sink.

Boeing processed a number of 2 micron material samples into individual emitters or arrays with 19 emitters. Metallization was applied and coatings were deposited. These arrays exhibited a threshold current of 11.0 amps with a slope efficiency of 176 mW/Amp for an array of 19- 100 micron x 1 millimeter cavity emitters and output power of 6.5 watts peak power at 50 amps (10%DC @ 10 C). Boeings electrically operated 2 micron laser efforts have led to the development of efficient, high power devices that are currently being considered for use in a number of Air Force programs.

2.4 OTHER LABORATORY EFFORTS

We successfully completed a spectral beam combining experiment in which we demonstrated the combining of three different wavelength lasers into a single collimated, spatially coherent output. The next step in this effort is to obtain three 2 micron pump sources so that we can optically pump all three mid-IR diodes in the combining experiment. Packaging and optimization will also be investigated.

We also worked with personnel from Wright Patterson AFB on several novel laser devices including a DFB, and an alpha DFB. Our efforts included providing processing and characterization expertise.

2.5 MAINTENANCE

Boeing provided maintenance support for the Mid-IR labs (rooms 110 and 116).
This support provided for facility and equipment upkeep and improvements, and safety and environmental compliance.

Boeing performed monthly safety inspections of labs 110 & 116 as well as the rework shop. Base safety/environmental meeting were attended. Haz-Mat/IAP procedures were kept up to date. All lab safety, hazardous waste and IAP inspection were passed.

Boeing personnel received training on TMDE/PMEL procedures and initiated placing appropriate items into the PMEL system.

We processed AF form 3952 for chemicals stored in Lab 116, and processed paper work to generate Profile Sheets for IAPs 187 and 202, to comply with the results of the UCI inspection

Other activity included designing a system to handle characterization data, to ensure data and programs were backed up, procurement of heatsink substrates to exacting tolerances, researching and evaluating replacement optics and infrared cameras to ensure the experiments were reliable, and repair of faulty equipment.

2.6 THEORY AND MODELING

Modeling and analysis of mid-infrared semiconductor lasers was supported through the development and refinement of empirical pseudopotential based methods applied to thin superlattice structures common in mid-infrared laser development work. Work on this method progressed in a number of areas.

We developed techniques, using a Fourier Transform Infrared Spectrometer (FTIR), for gain/index measurements to investigate the gain, antiguiding and absorption characteristics of several 1 micron and 1.4 micron superlattice quantum well designs in order to compare theory with experimental data.

We began modifications to our Empirical Pseudopotential Models (EPM) to incorporate highly strained material systems.

To improve our modeling codes we reviewed quantum statistical mechanics. We paid particular attention to the derivations of reaction equilibrium based on minimizing the free energy. We hope that these methods will be useful in calculating nonradiative rates in current superlattice W-active region designs.

We derived the necessary equations for lateral mode spatial filtering in the Hakki-Paoli FTIR set-up and completed a nonlinear least squares MathCad model for fitting Hakki-Paoli spectral data.

We are using quantum statistical mechanics in order to specialize chemical potential calculations to quantum well and super lattice structures. We are hoping that this will provide some insight into the nonradiative processes in our type-II quantum well lasers.

We have designed several new type-II lasers utilizing AlSb blocking layers and quantum well, hole doping (V-lasers). These new devices are an attempt to raise the current operating temperatures of our W-laser structures. We completed full gain & index calculations for these new W-laser and V-laser structures.

We revisited shooting methods for simulations of DFB/DBR laser structures in the Mid-IR. Our efforts resulted in the development of three new codes, a DFB/DBR linear code for finding the bare cavity modes, a nonlinear code for determining the modes of the gain saturated problem, and a final a code that determines the bare cavity mode contours. We have developed a new DFB/DBR model to investigate and optimize DBR laser structures grown on the current dilute waveguide type-II active regions. We assisted personnel from Wright Patterson AFB with the design of a 5 micron wavelength DFB laser.

We investigated new type-I & type-II active region designs using superlattices of InAsSb/GaAsSb. We also investigated possible laser structures in the group IV material system. Pseudopotential form factors were fit for both silicon and silicon/germanium binaries.

Both the EPM and gain codes were modified to calculate and store the nondegenerate conduction and valence band energies for our superlattice structures. A study was started to compare the degenerate and nondegenerate models. We looked at schemes for developing intraband laser transitions in type-II material systems (C2-C1 transitions).

We completed modeling of gain -vs- temperature at fixed inversion, gain -vs- temperature with adjusted inversion and gain -vs- frequency at fixed inversion for several type-II laser devices. These theory calculations were used to predict radiative and nonradiative loss mechanisms in our type-II laser structures.

We provided the Air Force with type-II W-laser active region designs for operating wavelengths at 2.4 microns and 2.7 microns. These devices were grown, processed and tested.

We developed a model for generating both linear and circular prolate eigenvalues and eigenfunctions. These models incorporate double precision eigenvalue/eigenvector algorithms, as well as sorting algorithms and a Gram-Schmidt orthogonalization algorithm.

We provided the Air Force with design parameters and waveguide loss studies for a standard 1.4 micron wide active region, 4 micron wavelength device with a mode killing region. This region serves to prevent the optical mode from touching the metallization layers utilized in our epitaxial down mounting configurations.

3.0 CONCLUSIONS

Boeing provided on-going operation and maintenance support for the DELS branch Mid-IR laboratories of the Directed Energy Directorate at the Air Force Research Laboratory. The laboratories were kept in compliance with safety and environmental regulations and consistently passed all inspections.

We utilized a semiconductor laser processing and characterization laboratory, which we had previously set up, to process and evaluate numerous prototype laser samples and material. Processing improvement were established which enabled us to provide better quality and repeatable laser devices, and we supplied state-of-the-art AR and HR coatings on these lasers. We led a successful effort to develop arrays of 2 micron lasers for optical pumping of mid-IR lasers.

Boeing also provided theory and modeling support for mid IR laser design and development. Our modeling of the electronic structure of superlattices for mid-IR semiconductors lasers materials has involved a solution technique based on the Empirical Pseudopotential Method, or EPM. This method showed particular strength in analyzing structures with short periods or thin layers, for which the effective mass method, based on $\vec{k} \cdot \vec{p}$ perturbation theory and the envelope function approximation, proved problematical. Based on that foundation, during the last year we have developed improved methods for incorporating the effects of coherent strain, as well as more accurate electron/hole wavefunction predictions and have applied these methods to several InAs-GaSb Type-II superlattices.

With this new version of the EPM well anchored, modeling efforts can concentrate on optimizing superlattice active regions for mid-IR semiconductor lasers in the 2-5 micron bands. These studies will include W-laser, as well as other type-II active regions. In particular, the new EPM method can be used to minimize the effects of inter-valance band absorption, and improve the device T_0, (device temperature sensitivity), of mid-IR active regions

4.0 PUBLICATIONS AND PRESENTATIONS

4.1 PUBLICATIONS

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“Comparing pseudopotential predictions for InAs/GaSb superlattices - art. no. 165307**”**, Dente, GC; Tilton, ML, PHYSICAL REVIEW B; OCT 15 2002; v.66, no.16, p.165307-5307

“High power and high brightness from an optically pumped InAs/InGaSb type-II mid-infrared laser with low confinement “, Kaspi, R; Ongstad, A; Dente, GC; Chavez, J; Tilton, ML; Gianardi, D, APPLIED PHYSICS LETTERS; JUL 15 2002; v.81, no.3, p.406-408

4.2 PRESENTATIONS

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“Comparing Pseudopotential Predictions for InAs/GaSb Superlattices**”,** Dente GC; Tilton ML; Ongstad A; Moeller C; Kaspi R, *Conference: 2002 Electronic Materials Conference, Santa Barbara CA*

“Investigation of Substrate Modes in InAs/InGaSb W-IA Structures**”,** Tilton ML; Dente GC; Chavez J; Gianardi D; Ongstad A; Kaspi R, *Conference: 2002 MOIMD, Annapolis MD*

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